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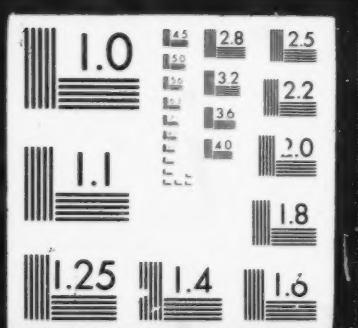

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VERTICAL TEMPERATURE DIFFERENCE OBSERVED OVER AN URBAN AREA

Gerard A. deMarrais

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1960

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VERTICAL TEMPERATURE DIFFERENCE OBSERVED OVER AN URBAN AREA

Abstract

Temperature differences recorded from thermohms at the 60, 170, and 524-foot levels on the WHAS-TV tower in Louisville are analyzed. The data indicate that the heat island of an urban area has a considerable effect on the vertical temperature differences observed at night so that the normal diurnal range of stability conditions encountered over an urban area is much smaller than that over open country.

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VERTICAL TEMPERATURE DIFFERENCE OBSERVED OVER AN URBAN AREA

Introduction

Since July, 1957, a vertical temperature difference measuring system has been in operation on the WHAS-TV tower in Louisville, Kentucky. The location of the tower in the commercial and business district of the municipality affords an opportunity to obtain rather unique quantitative information on the variation of temperature with height over an urban area. The temperature sensing units are at heights of 60, 170 and 524 feet above ground level; thus, data for a significant layer immediately above the rooftops and two strata within that layer are obtained. Data obtained at Idaho Falls, Idaho, and Rye, Sussex, England are included in order to show the contrast between open country and urban areas.

Tower Location and Instrumentation

The tower is at the southeast corner of an asphalt-covered parking lot which occupies most of the area in the city block. The position of the tower in relation to the downtown area is shown in Figure 1. As the average building height of the downtown area was estimated to be 60 feet, the lowest temperature measuring unit was placed at that height. Within several hundred feet of the tower no building is higher than 60 feet.

The temperature difference measuring system used is a Leeds and Northrup unit, which consists of 3 shielded, aspirated thermohm units connected to a Speedomax type-G recorder by means of mineral insulated cable. The system was calibrated when installed in July, 1957 and recalibrated in the spring and fall of 1958.

Other Tower Data

Many vertical temperature-difference data obtained from tower instrumentation in open country have been and are currently being collected. The data from Idaho Falls, Idaho, (DeMarrais, 1960) and Rye, Sussex, England (Best, 1952) which are shown in Figures 2 and 3, are typical (Augustin, 1904; Johnson, 1938; Singer, 1957; U. S. Weather Bureau, 1955). The Idaho Falls data are included to show a comparison of the temperature differences of surface layers, should one consider the rooftops as the effective surface of the downtown Louisville district; the Rye data provide a height for height comparison. Temperature difference records from flat, unpopulated areas show that surface inversions form almost every night and superadiabatic conditions exist during most of the daylight hours; weak lapse conditions (between isothermal and adiabatic) prevail during the transitional hours. The times of occurrence of the various temperature difference categories are so regular that they may be predicted with a fair degree of accuracy, e.g., at the Idaho Falls site surface inversions normally form shortly before sunset and break an hour or two after sunrise. However, only one limited investigation (Duckworth, 1954) indicates that such a pattern might not be the normal occurrence over the heat island of a city.

Louisville Data Versus Open Country Data

The 60- to 524-foot layer at Louisville does not show the daily temperature difference pattern demonstrated at non-urban sites. As seen in Figure 4 in which the average hourly temperature differences for alternate hours for each half-month are listed, superadiabatic conditions prevail during the daylight hours but no generalizations can be made for the

other hours. Average conditions at night vary from just about adiabatic to moderately-strong inversion. The individual nocturnal hourly observations vary from superadiabatic to strong inversion with slight lapse conditions occurring most frequently. Inversions are observed during approximately 10% of the nocturnal hours from mid-November to mid-April (cold half of year) and about 30% of the nighttime hours in the remaining part of the year.

One of the outstanding features of the bihourly, semimonthly plot of average temperature differences for the 60- to 170-foot stratum, as seen in Figure 5, is that only two of these averages show an inversion condition. During the nighttime hours in June, July and September, the averages are often greater than adiabatic, indicating that the 60- to 170-foot stratum is thermally unstable most of the time during those periods. The daytime averages are similar to those observed at Idaho Falls and Rye in that they are superadiabatic. The individual observations showed that inversions of 10 hours or longer occur on only 16 nights, with the months of October, November, December and April each observing three nights of such inversions. Superadiabatic conditions prevail for at least several hours during each day and occasionally persist for several days. Nocturnal temperature differences normally range from -0.1°F to -0.6°F.

The average temperature differences for the 170- to 524-foot stratum are seen in Figure 6. Superadiabatic conditions are again observed during most of the daylight hours. The nighttime hourly averages indicate that weak lapse situations prevail during the cold half of the year but inversions often occur in the remaining half. The inversions are most frequent

and intense during the late summer and early fall. The individual observations showed that inversions in this upper stratum are twice as frequent as those in the 60- to 170-foot interval. A weak lapse condition is the most prevalent situation at night.

Strata data from Idaho Falls are not available but the Rye investigation did provide comparative data. Figures 7 and 8 show the monthly average hourly temperature differences for the 50- to 155-foot and 155- to 350-foot strata. The lower stratum shows the same variation as the Rye 50- to 350-foot layer, i.e., inversions at night and superadiabatic conditions during most of the daylight hours. The upper stratum is different in that average daylight conditions are lapse but not superadiabatic. Thus, strata analysis also shows that the lapse rates over Louisville and a typical open country area are different.

Considering the parts of the 60- to 524-foot layer simultaneously the indications are 1) during the day Louisville experiences lapse rates which differ only slightly with those observed in non-urban areas, 2) during the night, Louisville experiences temperature differences unlike those observed in non-urban areas. Nocturnal inversions through the 60- to 524-foot height existed infrequently. During the warm half of the year an inversion was superimposed on a weak lapse condition about 15% of the time at night and with about the same frequency a weak lapse on top of a superadiabatic lapse rate was observed. With the exception of the rare situation in which a superadiabatic lapse rate existed all the remaining nighttime observations indicated that a weak lapse condition existed.

The Future

Similar analyses will be employed with data from Paris (Eiffel Tower), Detroit, and Tulsa. A preliminary analysis of the Eiffel Tower data (Angot, 1895) indicates that in the downtown area of Paris vertical temperature difference regimes are observed which are similar to those recorded over Louisville; all temperature difference averages for a five year period for the 2- to 123-meter level were negative except during August, September, and October. It is hoped that data from other cities will become available in the near future and that with records from about a half-dozen urban areas some generalities, possibly on a seasonal basis, could be made about the layer of air over urban areas. (Note: The author would appreciate receiving information on the availability of other urban vertical temperature difference records which are available for analysis.)

Conclusions

The vertical temperature differences observed at night over Louisville are considerably different from those observed over non-urban areas. Whereas surface inversions regularly occur at non-urban areas, they are comparatively rare over the urban complex. During more than half of the hours at night a lapse rate between isothermal and adiabatic in the 60- to 524-foot layer is observed and during 30% of the nighttime hours a discontinuous lapse rate in which the lower part of the layer is less stable than the upper part is observed.

Acknowledgements

The author is grateful to the Meteorology Section at the Robert A. Taft Sanitary Engineering Center for their cooperation in obtaining the data and rendering constructive criticism. Thanks are particularly due to Mrs. Ruth Umfleet who had the tedious task of seeing the report through the mechanics of several reorganizations and official reviews.

References

Angot, A., 1895: Resume des Observations Faites au Bureau Central Meteorologique et a la Tour Eiffel pendant les cinq annees, 1890-1894 (Annales, 1894).

Augustin, F., 1904: Der tagliche Gang der meteorologischen Elemente auf der Petrinwarte in Prag. Meteorologische Zeitschrift, 21, 113-129.

Best, A. C., E. Knighting, R. H. Pedlow, and K. Stormouth, 1952: Temperature and Humidity Gradients in the first 100 M. Over Southeast England. Geophysical Memoirs, No. 89, 4(11).

DeMarrais, G. A., and N. F. Islitzer, 1960: Diffusion Climatology of the National Reactor Testing Station. Idaho Falls Operation Office (AEC) Report IDO-12015.

Duckworth, F. S., and J. S. Snadberg, 1954: The Effect of Cities Upon Horizontal and Vertical Temperature Gradients. Bulletin American Meteorological Society, 35, 198-207.

Johnson, N. K., and G. S. P. Heywood, 1938: An Investigation of the Lapse Rate of Temperature in the Lowest Hundred Metres of the Atmosphere. Geophysical Memoirs, No. 77, 5(9).

Singer, I. A. and G. S. Raynor, 1957: Analysis of Meteorological Tower Data April 1950 - March 1952, Brookhaven National Laboratory. Brookhaven National Laboratory Report BNL 461 (T-102).

U. S. Weather Bureau, 1955: Meteorology and Atomic Energy. Washington, U. S. Government Printing Office, 169 p.

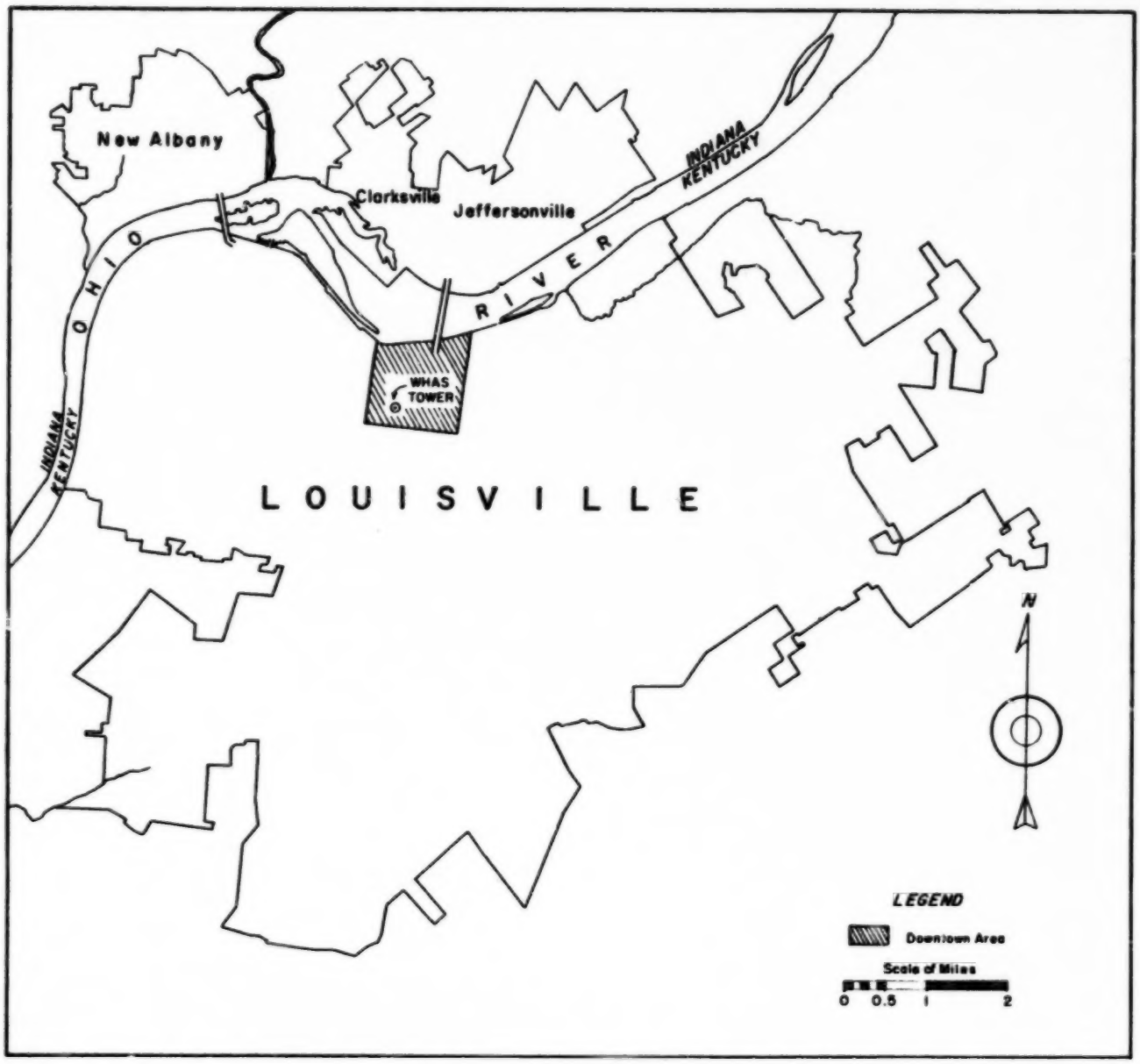


FIGURE I. LOCATION OF TOWER IN DOWNTOWN LOUISVILLE

	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY
Midnight	+6.3	+8.5	+5.7	+5.8	+4.3	+6.3	+6.3	+3.2	+3.5	+4.0	+4.8	+5.7
2	+7.6	+9.1	+6.1	+5.4	+4.5	+6.0	+6.3	+3.1	+3.4	+4.0	+5.5	+6.6
4	+8.2	+9.2	+6.7	+5.5	+4.5	+5.7	+5.9	+3.4	+3.7	+4.0	+5.6	+6.2
6	+8.0	+9.0	+7.1	+5.4	+4.4	+5.9	+5.7	+3.2	+3.5	+2.5	+2.0	+3.9
						SUNRISE →						
8	-2.6	-1.5	+0.8	+4.3	+4.2	+5.9	+5.4	-0.2	-1.9	-2.5	-3.0	-2.8
10	-4.0	-3.7	-3.2	-2.5	-1.0	+0.8	-1.3	-2.9	-3.4	-3.4	-3.9	-4.0
Noon	-5.0	-4.8	-4.0	-3.3	-2.3	-2.5	-3.0	-3.5	-4.0	-4.2	-4.5	-4.8
14	-4.8	-4.7	-3.9	-3.0	-2.5	-2.8	-2.9	-3.7	-4.1	-4.1	-4.7	-4.8
16	-3.9	-3.6	-2.7	-1.8	-1.2	-1.4	-2.0	-3.0	-3.3	-3.5	-3.8	-3.9
18	-2.2	-1.2	+1.0	+2.5	+2.3	+3.6	+0.8	-1.2	-1.9	-2.1	-2.4	-2.4
						SUNSET →						
20	+3.1	+5.6	+4.4	+4.3	+3.8	+6.7	+4.3	+1.6	+1.8	+1.3	+0.4	+0.8
22	+5.7	+7.5	+5.0	+5.1	+4.2	+6.6	+5.7	+2.8	+2.8	+3.5	+4.0	+5.1
24	+6.3	+8.5	+5.7	+5.8	+4.3	+6.3	+6.3	+3.2	+3.5	+4.0	+4.8	+5.7

Adiabatic = -1.3°F

FIGURE 2 - MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCES

IDAHO FALLS WBO, JANUARY 1955 - MAY 1958

$(T_{250} - T_5)$

	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY
Midnight	+2.01	+1.56	+2.69	+1.72	+1.19	+ .50	+ .21	+1.59	+1.46	+1.78	+1.58	+1.61
2	+2.08	+1.66	+2.81	+2.04	+1.44	+ .82	+ .22	+1.89	+2.01	+1.90	+1.71	+1.72
4	+2.21	+1.81	+3.14	+2.03	+1.20	+ .71	+ .38	+1.81	+2.31	+1.65	+1.60	+1.76
6	+1.49	+1.93	+3.25	+1.83	+1.12	+ .42	+ .21	+1.73	+1.88	+ .43	- .03	+ .31
						SUNRISE →						
8	-1.13	- .07	+1.98	+1.67	+1.06	+ .46	+ .03	+ .21	-1.02	-1.62	-1.58	-1.01
10	-1.68	-1.34	- .49	.00	+ .56	- .05	- .74	-1.47	-1.79	-1.92	-1.87	-1.29
Noon	-1.88	-1.53	-1.26	- .60	- .45	- .81	-1.48	-1.72	-1.88	-2.00	-2.03	-1.35
14	-1.82	-1.52	-1.16	- .60	- .53	- .83	-1.38	-1.50	-1.79	-1.90	-1.88	-1.36
16	-1.37	-1.33	- .48	+ .12	- .02	- .35	-1.02	-1.03	-1.56	-1.83	-1.61	-1.03
						SUNSET →						
18	- .76	- .32	+ .75	+ .79	+ .50	+ .19	- .33	+ .25	- .60	- .93	-1.03	- .45
20	+ .62	+1.06	+1.88	+1.14	+ .75	+ .34	- .02	+1.21	+ .39	+ .56	+ .60	+ .77
22	+1.45	+1.33	+2.61	+1.54	+ .89	+ .54	+ .21	+1.56	+1.06	+1.35	+1.45	+1.58
24	+2.01	+1.56	+2.69	+1.72	+1.19	+ .50	+ 2.1	+1.59	+1.46	+1.78	+1.58	+1.61

Adiabatic = -1.62°F

FIGURE 3 - MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCES

RYE, SUSSEX, ENGLAND, JULY 1945 - JUNE 1948

$(T_{350} - T_{50})$

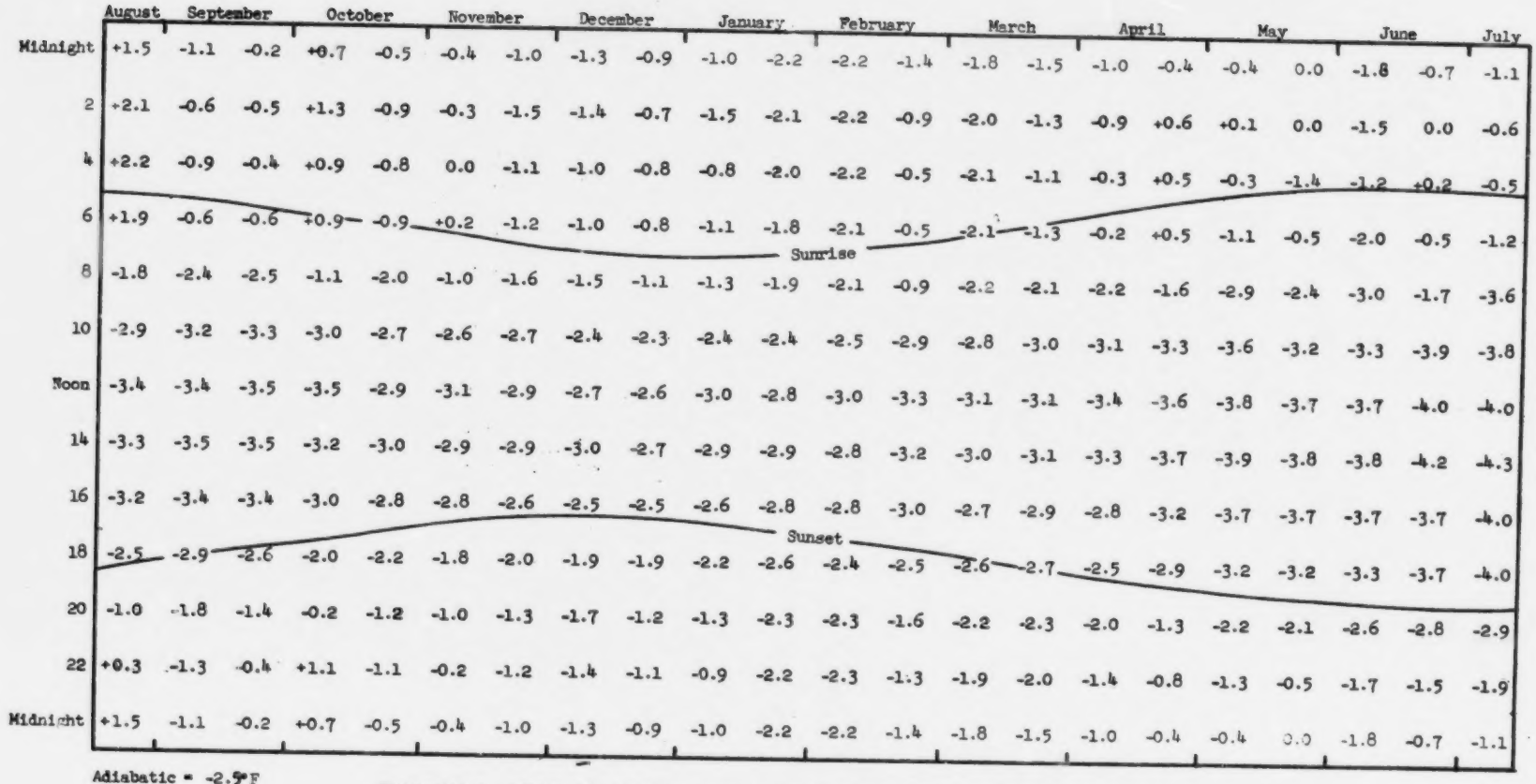
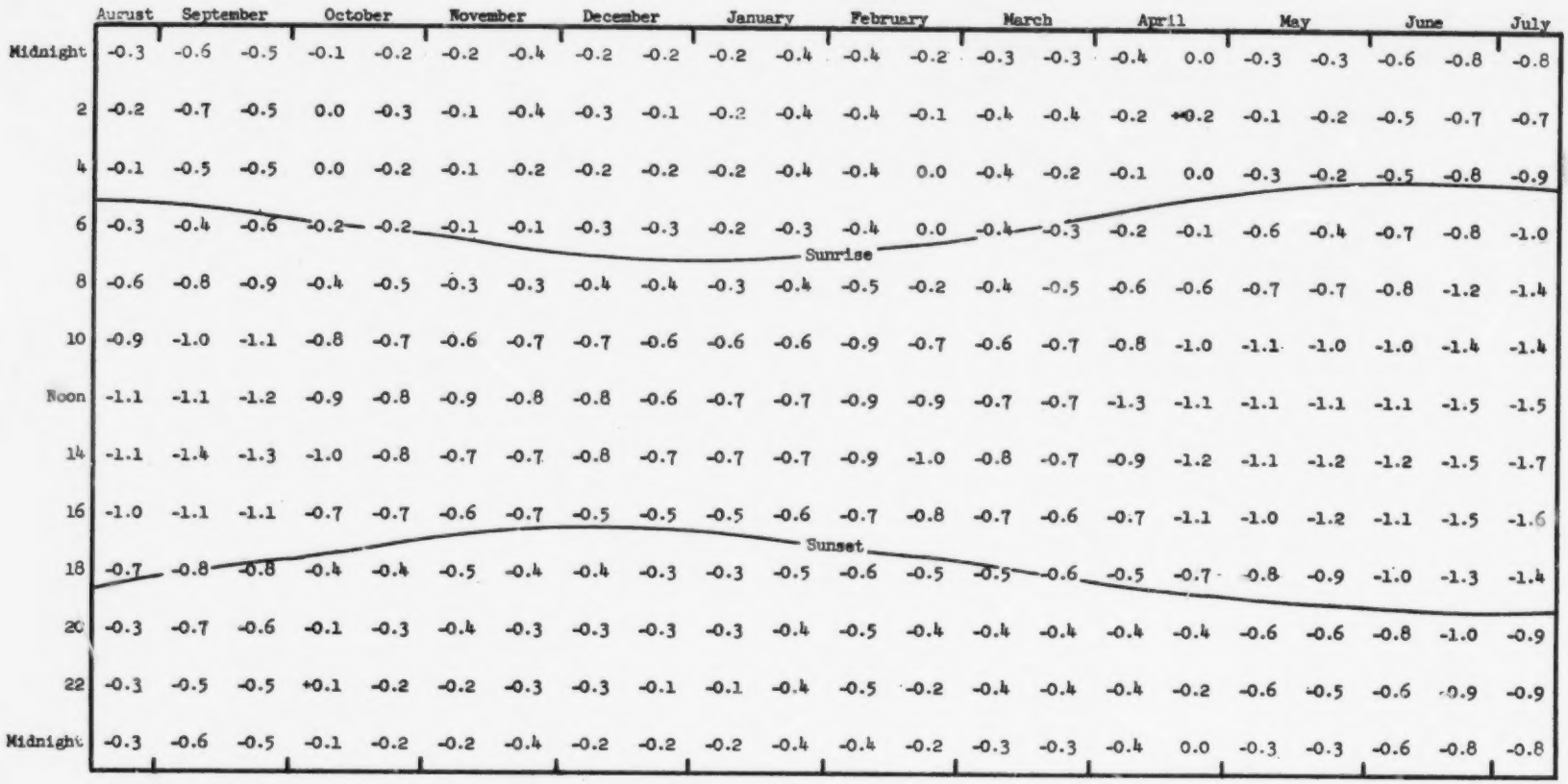


FIGURE 4- SEMI-MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCES
LOUISVILLE, 23 AUGUST 1957-15 JULY 1958

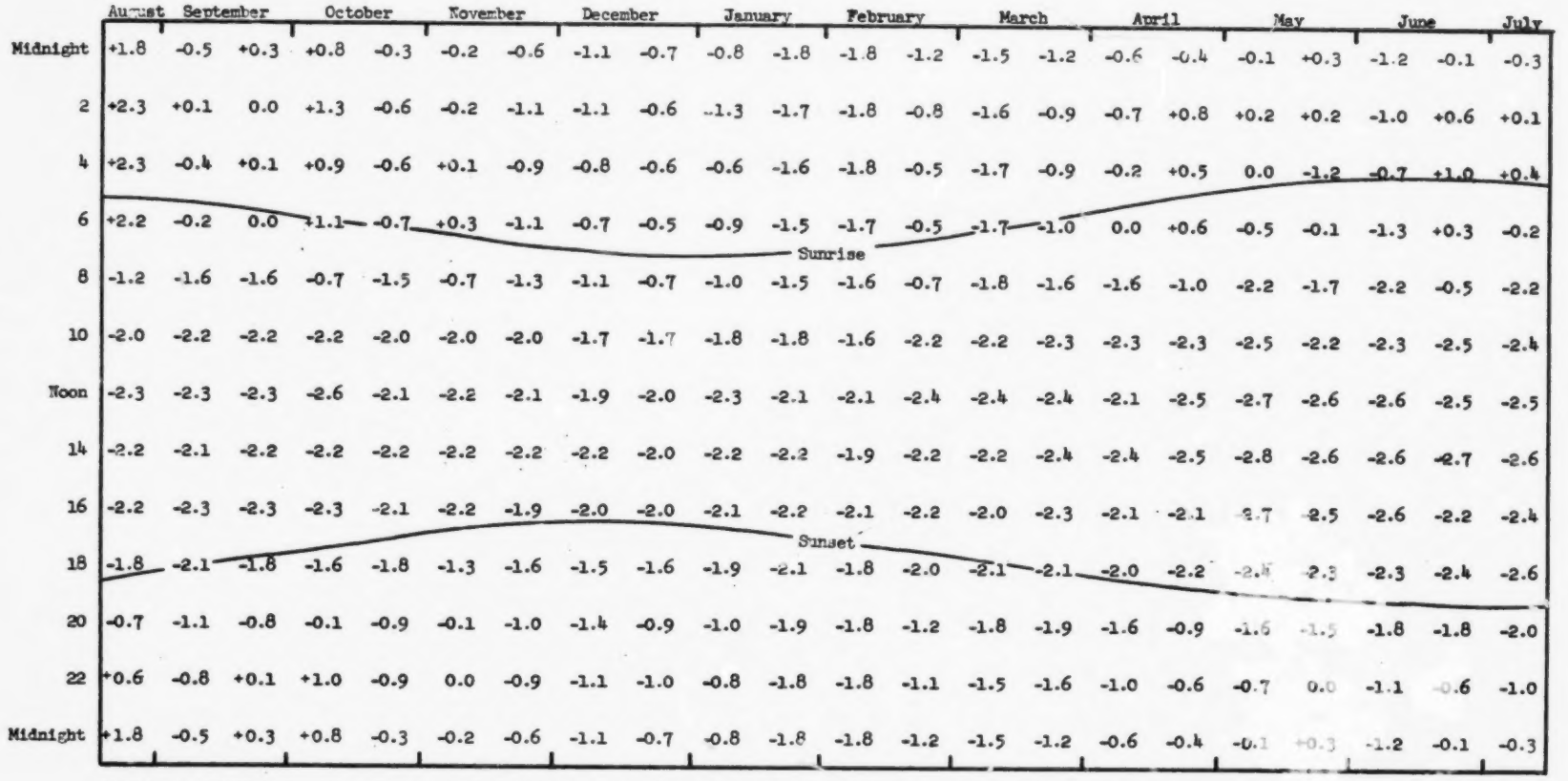
$(T_{524} - T_{60})$



Adiabatic = -0.6°F

FIGURE 5-SEMI-MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCES
LOUISVILLE, 23 AUGUST 1957 - 15 JULY 1958

$(T_{170} - T_{60})$



Adiabatic = -1.9°F

FIGURE 6-SEMI-MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCES
LOUISVILLE, 23 AUGUST 1957-15 JULY 1958
$(T_{524} - T_{170})$

	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY
Midnight	+1.14	+0.86	+1.82	+1.36	+0.81	+0.28	+0.19	+0.82	+1.18	+0.82	+0.79	+0.52
2	+1.12	+1.01	+1.95	+1.48	+0.90	+0.54	+0.16	+0.88	+1.54	+1.11	+0.94	+0.71
4	+1.26	+1.19	+2.28	+1.45	+0.81	+0.38	+0.24	+1.02	+1.77	+0.97	+0.91	+0.69
6	+0.74	+1.21	+2.27	+1.34	+0.78	+0.24	+0.19	+1.00	+1.28	+0.18	-0.19	-0.36
8	-0.89	-0.29	+1.17	+1.04	+0.77	+0.27	+0.09	+0.13	-0.79	-1.01	-0.90	-0.96
10	-1.15	-0.91	-0.31	+0.05	+0.34	-0.08	-0.49	-0.74	-1.07	-1.19	-1.19	-1.17
Noon	-1.24	-1.02	-0.68	-0.30	-0.25	-0.49	-0.91	-0.77	-0.91	-1.08	-1.10	-1.21
14	-1.19	-1.02	-0.59	-0.31	-0.23	-0.42	-0.81	-0.71	-0.87	-1.13	-1.32	-1.33
16	-0.88	-0.81	-0.23	+0.27	+0.08	-0.15	-0.52	-0.57	-0.75	-0.88	-0.86	-1.05
18	-0.49	-0.19	+0.64	+0.73	+0.42	+0.14	-0.09	+0.13	-0.22	-0.48	-0.59	-0.64
20	+0.46	+0.69	+1.40	+0.87	+0.56	+0.18	+0.15	+0.67	+0.51	+0.27	+0.37	+0.25
22	+0.84	+0.82	+1.89	+1.19	+0.65	+0.35	+0.24	+0.86	+0.80	+0.67	+0.74	+0.51
24	+1.14	+0.86	+1.82	+1.36	+0.81	+0.28	+0.19	+0.82	+1.18	+0.82	+0.79	+0.52

SUNRISE →

SUNSET →

Adiabatic = -0.57°F

FIGURE 7 - MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCE

RYE, SUSSEX, ENGLAND, JULY 1945 - JUNE 1948

$(T_{155} - T_{50})$

	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY
Midnight	+0.87	+0.70	+0.87	+0.48	+0.38	+0.22	+0.02	+0.77	+0.28	+0.96	+0.79	+1.09
2	+0.96	+0.65	+0.86	+0.56	+0.54	+0.28	+0.02	+1.01	+0.47	+0.79	+0.77	+1.01
4	+0.95	+0.62	+0.86	+0.58	+0.39	+0.33	+0.14	+0.79	+0.54	+0.68	+0.69	+1.07
6	+0.75	+0.72	+0.98	+0.49	+0.34	+0.18	+0.02	+0.73	+0.60	+0.25	+0.16	+0.67
8	-0.24	+0.22	+0.81	+0.63	+0.29	+0.19	-0.06	+0.08	-0.23	-0.61	-0.68	-0.05*
10	-0.53	-0.43	-0.18	-0.05	+0.22	+0.03	-0.25	-0.73	-0.72	-0.73	-0.68	-0.12*
Noon	-0.64	-0.51	-0.58	-0.30	-0.16	-0.32	-0.57	-0.95	-0.97	-0.92	-0.93	-0.14*
14	-0.63	-0.50	-0.57	-0.29	-0.30	-0.41	-0.57	-0.79	-0.92	-0.77	-0.56	-0.03*
16	-0.49	-0.42	-0.25	-0.15	-0.10	-0.20	-0.50	-0.46	-0.81	-0.95	-0.75	+0.02*
18	-0.27	-0.13	+0.11	+0.06	+0.08	+0.05	-0.24	+0.12	-0.38	-0.45	-0.44	+0.19*
20	+0.16	+0.37	+0.48	+0.27	+0.19	+0.16	-0.17	+0.54	-0.12	+0.29	+0.23	+0.52
22	+0.61	+0.51	+0.72	+0.35	+0.24	+0.19	-0.03	+0.70	+0.26	+0.68	+0.71	+1.07
24	+0.87	+0.70	+0.87	+0.48	+0.38	+0.22	+0.02	+0.77	+0.28	+0.96	+0.79	+1.09

SUNRISE

SUNSET

* Authors suggest that these may be due to sea breeze effect.

Adiabatic = -1.05°F

FIGURE 8 - MONTHLY AVERAGE HOURLY TEMPERATURE DIFFERENCE

RYE, SUSSEX, ENGLAND, JULY 1945 - JUNE 1948

$(T_{350} - T_{155})$